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Materials Processing in Low Gravity
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FINAL REPORT

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I wish to express my gratitude to the many UAH workers and students who have worked with me in performing various phases of this contract; to Mr. Mark Tscherneshoff for his initial efforts for assembling the drop tube and drop tower experiments, and to the NASA personnel who have helped us to perform these tasks. In particular, Mr. Roger Chassay, Dick Black, and Bob Mixon in the projects office, Dr. Robert Shurney in the KC-135 experiments, and the scientists in SSL who helped in many ways to perform low-gravity experiments. Also, we wish to thank the scientific investigators who worked with us in performing their experiments; most notably the John Deere & Company, Dr. Doru Stefanescu at the University of Alabama, and Dr. Robert Bayuzick at Vanderbilt.

Introduction

The Materials Processing in Low Gravity Program began with a major emphasis on providing technical expertise in improving the capabilities of scientists and engineers at Marshall Space Flight Center to do research in low gravity using the principal non-space environments, the KC-135, the F-104, the Drop Tower and the Drop Tube. The latter two facilities are housed in Building 4510 at Marshall Space Flight Center, while the two aircraft fly out of Ellington Field, Texas and Dryden Field, California, respectively. Starting with Mr. Ed Luttges, Guy Smith, and myself we initially began working Dr. Mary Helen Johnston and The John Deere Company in developing experimental hardware to solidify cast iron samples in low gravity aboard the KC-135. Soon after the initial contract began, we were able to hire Mr. Mark Tscherneshoff to assist in setting up technical capability at the Drop Tube and Drop Tower. Mark was able to utilize student workers to assist him in this effort. The initial efforts included fabrication of the necessary instrumentation to bring up the Drop Tube and to begin construction of a drop tower package for measuring critical wetting for Dr. Bill Kaukler, at that time a USRA scientist at Space Science Laboratory.

The original scientific/management structure set up to provide an SSL interface for managing the low gravity experiments included Dr. Pete Curreri to provide scientific lead for all flight experiments, Mike Robinson to provide lead on all drop tube experiments, and Tom Rathz to provide lead on Drop Tower experiments. In addition the Test Laboratory provided lead for all facility requirements and the Project Office or Space Science Laboratory provided overall contract management responsibility. In the beginning every facility change required several levels of personnel to respond to almost any desired implementation or modification, particularly at the drop facilities. Most improvements to the system that required more than a simple purchase, build and implement by UAH at the drop facilities moved very slowly. Since that time changes within the system have provided some improvements in response time within the scientific and facility responsibilities, but the overall structure has remained.

The current strategy has led to the Experimental Carriers Branch of the Spacelab Payload Office to provide the technical contract management for the effort, a change that has improved the overall responsiveness of the system to the tasks required in order to provide low gravity and containerless processing capability to a wide audience. The unique physical and economical advantages of the low gravity facilities can be realized only when productive state-of-the-art science can be performed at the site. This goal is constantly being pursued by all persons associated with this contractual effort.

Technical Tasks

In the scope of this project we have fabricated a large number of systems which are available for use in all four of the facilities. Although several monographs have been submitted to MSFC for use as users' manuals, we will identify some of the systems here.

KC-135 Tasks

The original work involved modifying the "paint-can" furnace which was used to solidify cast iron samples for The John Deere Company. Many problems existed with this apparatus in terms of logistics required to perform the experiment aboard the KC-135 during low-G manuevers. Although the experiments were in no way reproducible, the short low-G time of the KC-135 provided the motivation for not using this apparatus for more experiments. Since the sample size preferred by the scientific investigators was too large to solidify properly in the window of the KC-135's trajectory, there was a decision made to do the experiments on the F-104. The "paint-can" apparatus is still available, although we do not consider it useable for KC-135 experimentation without a large amount of modification.

Most of our KC-135 work has been concerned with designing, fabricating, modifying, and fine-tuning the Automated Directional Solidification Furnace (ADSF). Dr. Peter Curreri, Dr. Mary Helen Johnston and Dr. Robert Shurney have been intricately involved in all phases of this activity. Two versions of a user's manual, one the original and then an up-dated version, have been submitted as manuals for this furnace. Two significant advantages of this furnace over the previous attempts to solidify cast iron samples were the "automated" concept and the reproductibility of experiments. Performing even simple tasks during the low gravity parabolas is not easy for the flight crew and automating as many functions as possible makes the experiments more predictable and repeatable.

Guy Smith, who is the principal person responsible the technical aspects of the ADSF, and Dr. Gary L. Workman are the two persons who normally fly the experiment. A number of experiments besides cast iron have been processed in the furnace during this contract period. Principal investigators have been the University of Alabama, Pratt & Whitney, General Motors, and others. Classes of samples include immisible compositions, alloys, and others. Dr. Peter Curreri maintains the information defining each experiment's data objectives and results. We have been extremely fortunate to have Dr. Robert Shurney guide us in performing KC-135 experiments and trying to improve with each mission. Through this contract UAH has participated in 19 different KC-135 trips to Ellington Field and flown on 17 of them. Normally three missions are flown during each trip.

F-104 Tasks

Two series of experiments utilizing the F-104 airplane have been flown by UAH in conjunction with The John Deere Company and Bethlehem Steel as the industrial investigators and Dr. Stefanescu at UA and Dr. Curreri at MSFC as scientific investigators. The first series of experiments were not solidified in low G and a large amount of white iron formed, indicating that the cooling rate was too fast. Guy, with assistance from Dr. Curreri, worked toward reducing the rapid helium flow onto one spot on the sample and instead came up with a design which allowed more uniform cooling of the total sample; much like a casting would behave. A report of these experiments has been submitted as a user's guide and as a TM during the timeframe following the experiments. In the second series, using the more uniform flow, six of the samples were clearly solidified in low G. To our knowledge no analysis of these samples has been undertaken.

The F-104 experimental furnace used for bulk casting experiments is self sustaining and is available for bulk casting in any environment, including the KC-135. It does feature an expendable furnace arrangement, using kanthal heating element wire, instead of platinum like the other furnaces. The furnace was designed in conjunction with Mr. Richard Poorman of

MSFC. Since the furnace uses 28v DC, it would fit in very well with the KC-135 experiments power requirements.

Drop Tower Tasks

During this contractual effort, we have also been able to work with the Test Laboratory personnel in reviving the Drop Tower as a MSFC facility for low gravity experiments. To date we have been constrained by some of the systems which were implemented several years ago and would have replaced them except for the lack of funds. The areas which cause the most down-time are the structural aspects of the dragshield and the electrical/telemetry systems. The structural aspects are the responsibility of MSFC and we have no control over the facility at all. We have replaced the horse- hair mats in the catch-tube in order to minimize any impact damage to the drag shield itself.

The original NiCd batteries failed very early in our effort and we have used Gel Cell batteries since then. They are much less expensive and have worked well. The telemetry system provided a bottleneck in many occasions due to personnel requirements and transmission protocols. Since the telemetry system monitors the pressure within the thruster vessel, safety requirements mandates that the system be used. In general we have tried to off-load as much electronic data requirements away from the telemetry system as possible. For instance, we have purchased an on-board data acquisition system for recording temperature and accelerometer data during drops, which can then be dumped into a computer for analyzing at any point in time.

To date two different experimental packages have been built for use in the Drop Tube facility. The critical wetting experiment consists of large constant temperature bath with optical windows enabling photographic techniques to record images of test ampoules during the drop. By heating the bath up to a pre-determined temperature and then dropping the package, one is able to record wetting angles of the materials used in the tests. Dr. William Kaukler is the scientific investigator for this experiment. We have made a large number of modifications to the package in order to optimize desired experimental characteristics during the drops.

The other package which has been prepared for drop tower use is an alloy solidification experiment in which Dr. M.K. Wu of UAH is the principal investigator. Using a furnace designed and built by Mr. Billy Aldridge of SSL, we have intergrated the package into a fairly flexible furnace for the drop tower. The experiment uses a helium gas quench to cool the molten sample below its solidification temperature in the 4 seconds of low gravity. As in the previous package, we are constantly modifying the systems in order to improve the capability of the package.

Drop Tube

The facility that gets the most attention and probably will receive the most use is the drop tube itself. The requirements to process a sample are very minimal in scope as long as the melting characteristics of the specimens are easily accomplished using either the electromagnetic levitation furnace or the electron beam furnace. These furnaces are not unique by themselves, however, the additional capability of letting the solidification of the molten material occur during a 300 foot fall does provide unique opportunities for the scientific investigators interested in rapid solidification and containerless processing phenomena.

As long as all systems are functioning properly, the processing of samples can go as quickly as every 15 - 30 minutes, which can provide a very large throughput for generating materials specimens. Unfortunately, a system that large, in an uncontrolled environment, does not seem to go for too long before problems occur. The responsibilities for maintaining the facility are fairly straight forward in that NASA personnel are available for repair and maintenance tasks that fall under the facility responsibility, and if it is a scientific apparatus, UAH normally is responsible for the repair or replacement of defective components. On a number of occasions UAH has replaced components which was not their responsibility, as when the replacement parts are more quickly obtained by going through the contract rather than trying to find funds internally within NASA. A better arrangement might be to allow UAH to repair and replace some aspects of the facility, particularly if UAH can get the job done more quickly.

The drop tube represents a challenging laboratory instrument in that it consists of many different subsystems which all have to work at the same time in order for the facility to function properly. This includes sample temperature measurements during the melt and estimations of sample temperatures during the drop, time determinations correllated with any observed undercoolings and the ability to control the temperature of a molten sample within the furnace. The group of scientists who are interested in drop tube research work with the UAH project staff to continuously improve upon or add to the capabilities in these areas. A Drop Tube Procedures manual has been written for persons who actually use the facility. It has already been submitted as an interim report and should be updated whenever necessary.

Just before the end of this contract, an extended equipment purchase did provide for better temperature measurement of molten drops, capability at lower temperature estimation of falling drops and a mass spectrometer system to determine moisture or oxygen in the drop tube furnace. These systems will be fully intergrated into the drop tube facility during the next contract period.

The current log of Drop Tube experiments indicates that through this contract we have participated in some 124 drops in only 31 drop days during 1984, while in 1985 the number of drops exceeded 500, including test drops. The major barrier to throughput in the facility is keeping the tube up. Mike Robinson, as mentioned earlier and John Theiss are two persons in SSL who have been extremely helpful in maintaining certain parts of the system. John has contributed many times to helping to solve maintenance problems, particularly with respect to the electromagnetic levitation section of the tube.

Proprietary Data Requirements

In order to satisfy the user capacity for the low gravity facilities that NASA is expecting, there needs to be in place a capability to protect the scientific or industrial investigator from unauthorized access or usage of experimental data or results. At the current time there has been more activity from academic investigators wanting to protect data from unauthorized access than from industrial investigators. In the academic case publishable data is the objective, not marketable products; however the intent of the need is the same. During the course of this contract, UAH has had minimal problems in maintaining control over such data requirements. Other than the original objectives defined for the KC-135 and F-104 experiments, few investigators have included UAH personnel in any type of discussion about experimental objectives other than composition of the current samples and desired temperatures. Also, the handling of the experimental results has been different for the drop facility experiments and for aircraft experiments. UAH has been responsible for cutting and etching samples processed aboard the aircraft, whereas we do nothing of that type of activity for drop tube or drop tower specimens where processed samples and any quantitative data are sent to the scientific investigator with very little analysis on the part of UAH. During the flight experiments with The John Deere Company, we had to have a better understanding of the experimental objectives in order to better refine the experimental equipment in order to meet those objectives. In general, only the appropriate NASA personnel are aware of the overall objectives of the drop tube experiments.

UAH personnel have respected proprietary requirements by not publishing any scientific articles relating to experiments performed for any of the scientific investigators. In those cases where we felt a presentation was appropriate, we have either joined as co-authors on a paper or presentation or in one case we asked the appropriate Principal Investigators to make a presentation at the American Society for Engineering Education Annual Conference in the summer of 1985. This approach can be written up into a general guideline which is easily followed by the contractor personnel. UAH also has benefitted from not really having anyone associated with parallel experiments so as to be in a competitive position in any of experiments currently included in the academic or the industrial environment. As time goes on this could change.

A recommended approach is to basically follow the lead of the scientists who are working in the containerless processing and rapid solidification areas of research. By establishing an open communication between the individuals as to who is doing what experiments and why, peer group leverage determines what experiments each proposes and the appropriate NASA person then provide leadership in determining the overall range of experiments which uses the NASA facilities. On the other hand, there will be industrial groups which desire that absolutely no one know what their experiments are. Then each case has to be handled in a different way in order to maximize processing of the samples. Obviously if the persons running the experiment don't have sufficient information to perform the experiment properly, no one benefits. Consequently it is suggested that appropriate NASA personnel obtain from each potential facility user the extent of data rights desired by the investigator (as they currently do) and that only the necessary information for processing of the samples be passed on to the contractor responsible for implementation of the experiment. The contractor will then be able to abide by the investigator's proprietary data requirements.

Summary

The UAH efforts to implement low gravity experiments in materials processing at the Drop Facilities at Marshall Space Flight Center and on the two NASA aircraft has progressed through a first phase which involved building up a number of systems and utilizing them at the above facilities. The evolution of the project results in more capability as each new improvement to a particular facility occurs. The thrust to perform low gravity and/or containerless experiments on Earth will continue to increase as the concept of a space station type facility approaches closer to reality. To this end the KC-135, the F-104, and the Drop Facilities at MSFC will continue to provide a less expensive way to distinguish between good experiments and bad, to determine parameters affected by gravity, and to provide a test-bed for experimental hardware before it is launched into orbit.

Progress is constantly being made at improving the capabilities of the facilities and hopefully progress will be maintained in the future. The materials processing in low gravity programs need such facilities as a stepping stone to space and UAH will continue to assist in this endeavor in whatever form as needed.